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GEARBOX SUB-SYNCHRONOUS RADIAL VIBRATION AT THE TRAIN 1ST TNF, INDUCED BY CYCLIC PROCESS PHENOMENA

Authors

Paola Rotondo
Principal Engineer
Electrical System Dynamics
GE Oil&Gas - Florence, Italy
paola.rotondo@ge.com

Gaspare Maragioglio
Engineering Manager
Shaft Line Integration
GE Oil&Gas - Florence, Italy
gaspare.maragioglio@ge.com

Gianluca Boccadamo
Lead Engineer
Shaft Line Integration
GE Oil&Gas - Florence, Italy
gianluca.boccadamo@ge.com

Valerio Depau
Engineering Team Leader
Field Testing & Inspection
GE Oil&Gas - Florence, Italy
valerio.depau@ge.com

Paola Rotondo is currently a Principal Engineer for Electrical System Dynamics at GE Oil&Gas, Florence, Italy. She is responsible of development, optimization and standardization initiatives in the electrical system area including simulations and test. She deeply works on electromechanical interactions on electrified trains for Oil&Gas applications.

Gaspare Maragioglio is currently the Engineering Manager of the Shaft Line Integration Team for GE Oil & Gas Nuovo Pignone, in Florence, Italy. He is now responsible for technical selection and design verification of flexible and rigid couplings, load gears and auxiliary equipment, with particular focus on the train rotor-dynamic behavior, torsional and lateral.

Gianluca Boccadamo is currently Design Engineer in the shaft Line Integration Team for GE Oil & Gas Nuovo Pignone, in Florence, Italy. He is responsible for the requisition tasks and the integrated rotor-dynamic studies. He supports also NPI projects, manufacturing and test department for full speed full load string tests.

Valerio Depau Valerio Depau is Field Testing Technical Leader in the Diagnostic Engineering Department at GE Oil &gas, in Florence, Italy. He is responsible for critical troubleshooting activities at site that involve advanced measurements techniques.

Presentation summary

1. Introduction
2. Train configuration & characteristic data
3. Observed vibration behavior at site
4. Observed ripple on 3rd stage flow
5. RCA - Electro-mechanical interaction
6. RCA - LCI drives inter-harmonic excitation
7. RCA - Speed ripple to 1st TNF excitation
8. Gear shafts mechanical response
9. Site corrective action and outcomes
10. Wrap-up – Cause/effects correlation
11. Highlights/Lessons Learnt

1. Introduction

What:

Anomalous gear shafts vibration @ 1st TNF observed in a motor-compressor train, running at stationary operating conditions.

LCI Variable Frequency Drive is a potential cause of torque ripple,

BUT

at the conditions where the vibration occurred no LCI excitation was expected.

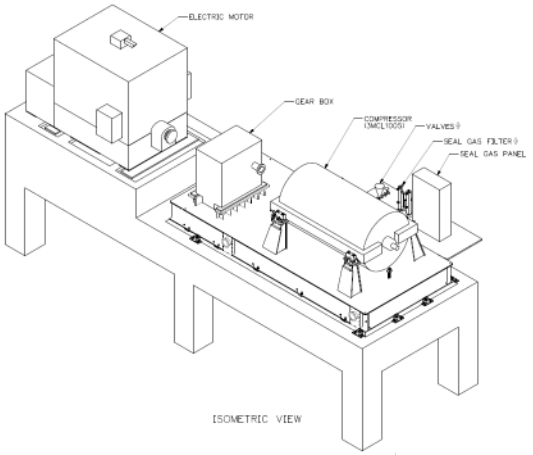
Potential issues:

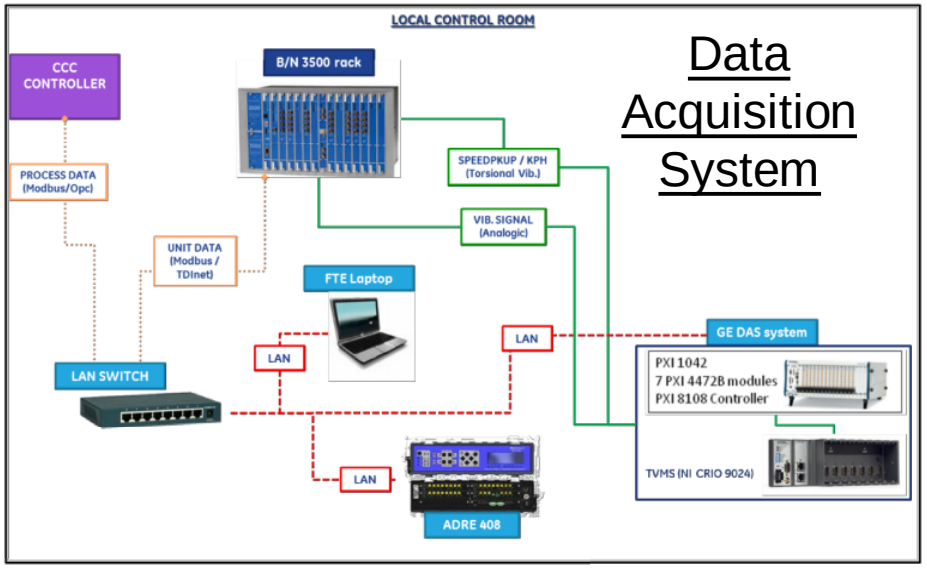
- Cyclic stresses on gear shafts → Possible component damages.
- Pulsating torque at 1st TNF → Fatigue on torque transmission devices.
- Vibration over allowable limits → Reduced train availability at site.

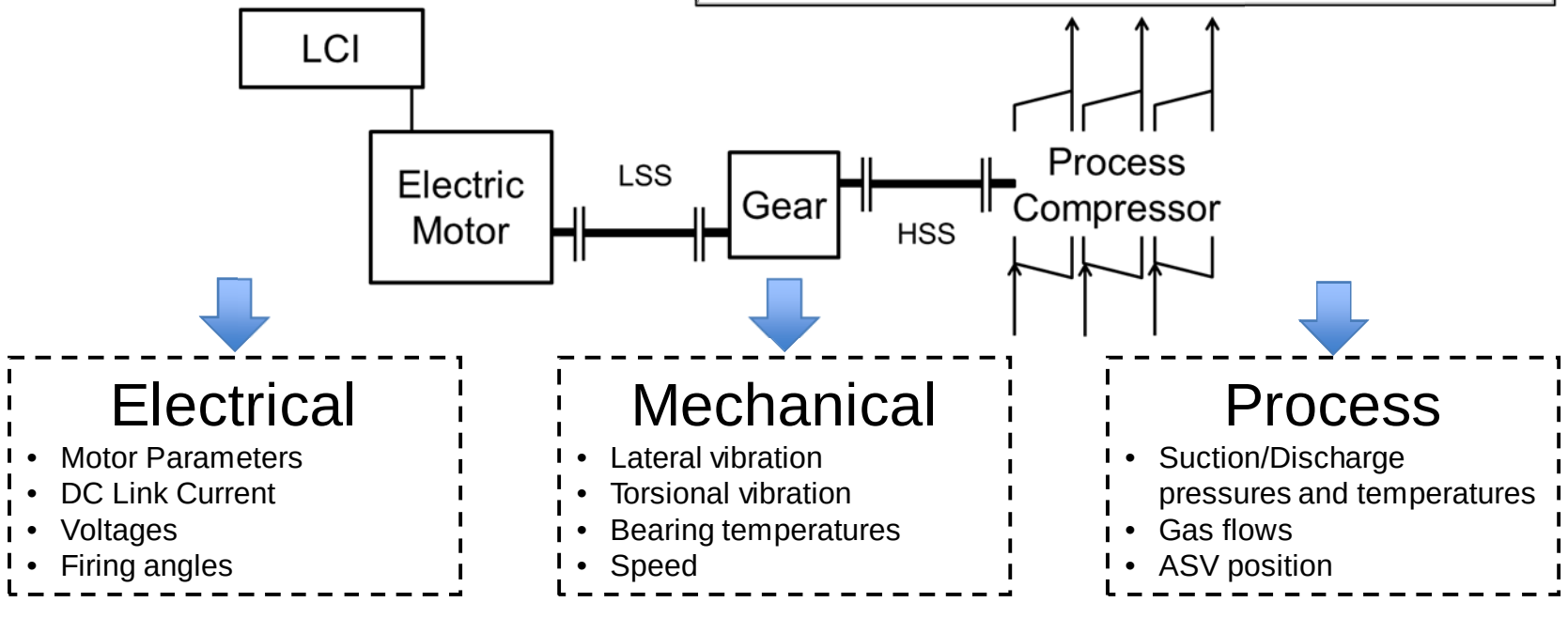
Purpose of the case study:

Bring to the attention of the Oil & Gas Community an example of electromechanical interaction in the electrified systems, which manifest itself as gear shaft radial vibration while it is induced by a cyclic process phenomenon.

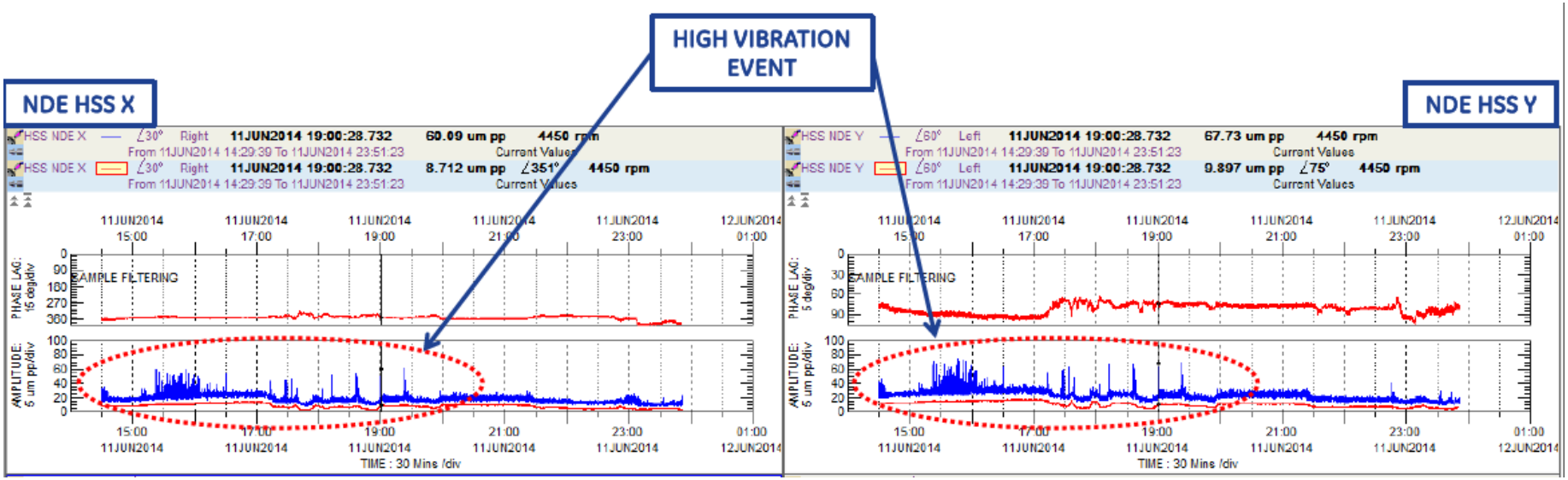
2. Train configuration & characteristic data



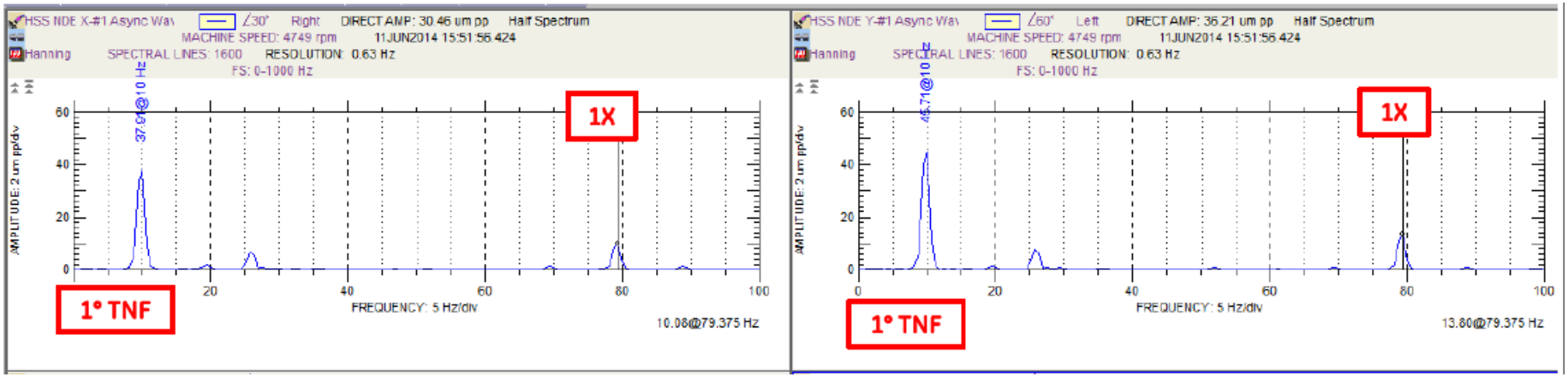




3. Observed vibration behavior at site



High vibration observed on gearbox HSS at specific operating speeds

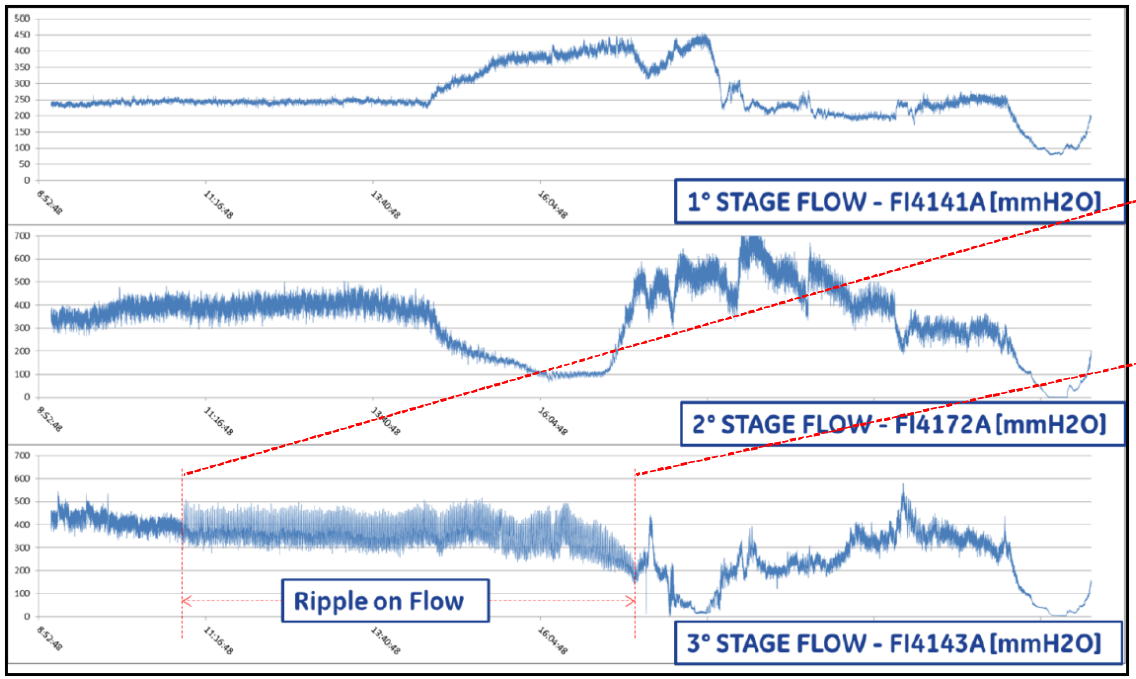


Vibration frequency matching 1st TNF (approx 10 Hz)

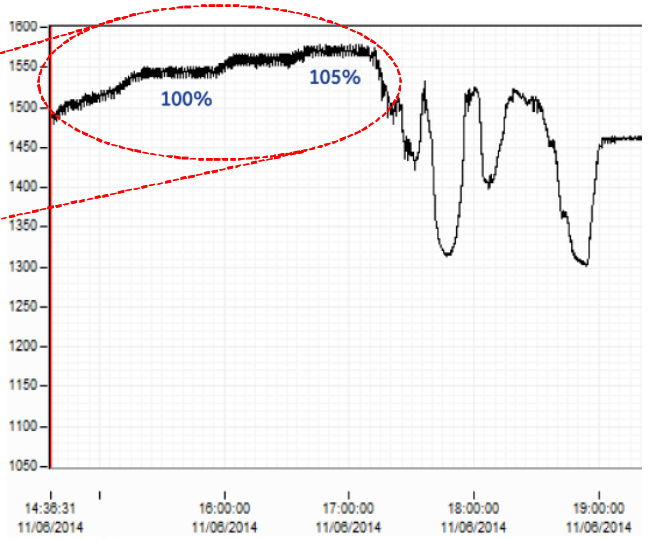
4. Observed ripple on 3rd stage flow

Oscillating process flow was observed on compressor 3rd stage, which in turn induced ripple in train speed.

Cause:
faulty behaviour of the 3rd stage antisurge valve, which worked in a sticky way.



Process gas flow



Speed trend [rpm]

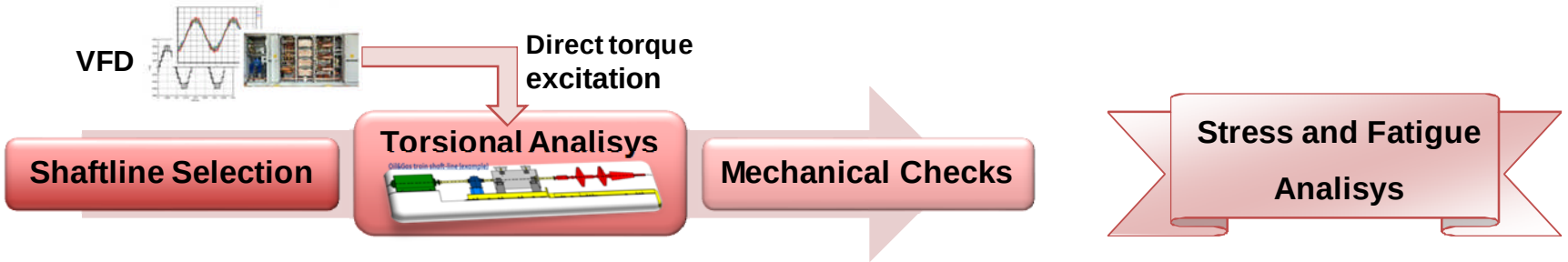
5. RCA - Electro-mechanical interaction

VFDs can have electromechanical interactions with shaft line

Main potential causes for those interactions can be summarized as follow:

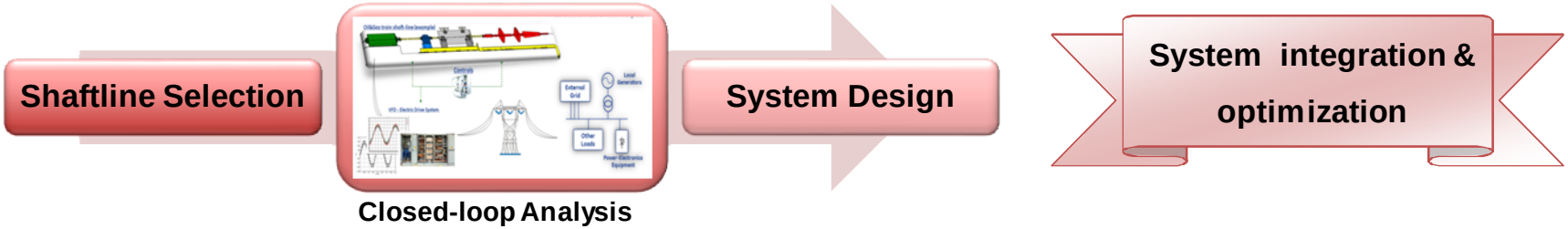
- **Direct Torsional Excitation from VFD**

  VFD air gap torque harmonic components can directly excite train torsional natural frequencies (TNF's) @ certain speeds



- **System closed loop behavior (Electrical, Mechanical, Controls…)**

  Control settings and/or mechanical response can influence the overall system torsional response



6. RCA - LCI drives inter-harmonic excitation

LCI (Load Commutated Inverter) drive introduces on train shaft Direct Torsional Excitations (e.g. interharmonics).

Those inter-harmonic excitation frequencies (in the motor air gap torque) are function of the grid frequency and of the motor speed:

fe = Ci * |fn – fm|

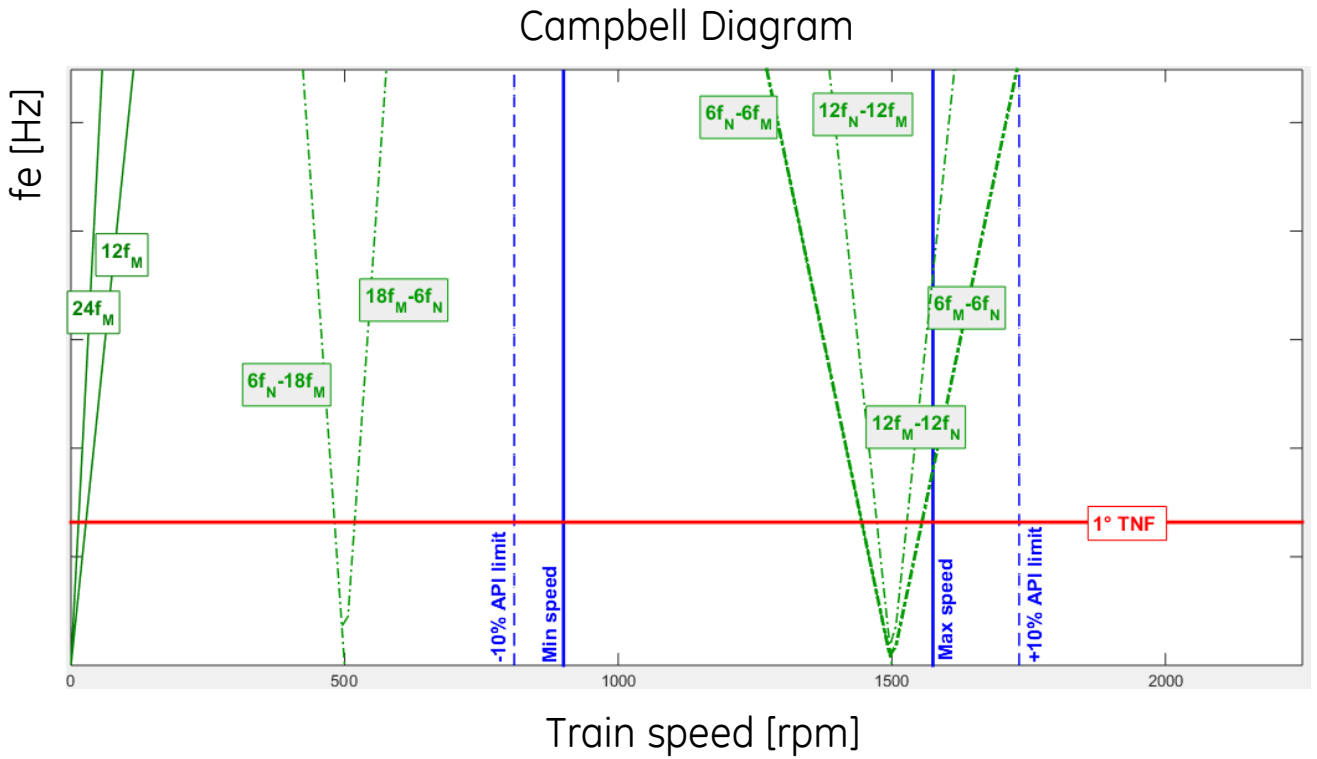
where

fe = excitation frequency [Hz]

fm = drive output frequency [Hz]

fn = grid frequency [Hz]

Ci = constant linked with drive topology

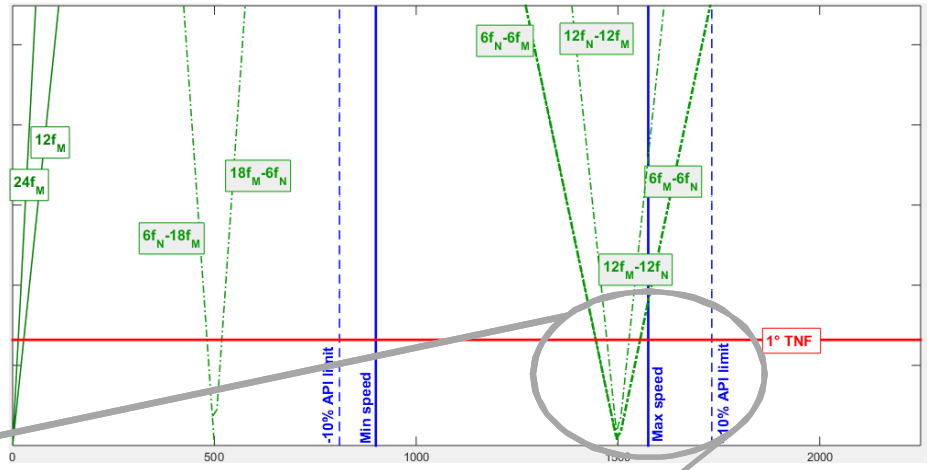


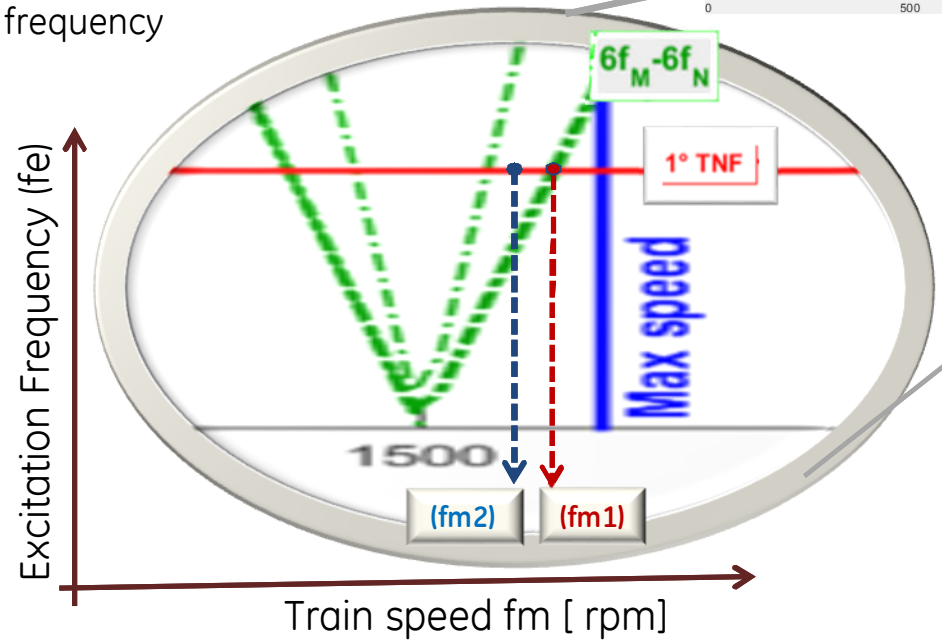
7.1 RCA - Speed ripple to 1st TNF excitation

The LCI inter-harmonics can excite train TNFs at certain speed.
If the motor speed changes also the **fe** changes (linear transfer function).

For example considering
fe = (6 fm – 6 fn) = 1st TNF
where
fm = train speed * pole pairs / 60
fn = grid frequency

Campbell Diagram





- (6 fm – 6 fn) LCI excitation was expected at **fm =fm1**
- At speed **fm=fm2** no LCI ecitation was expected.

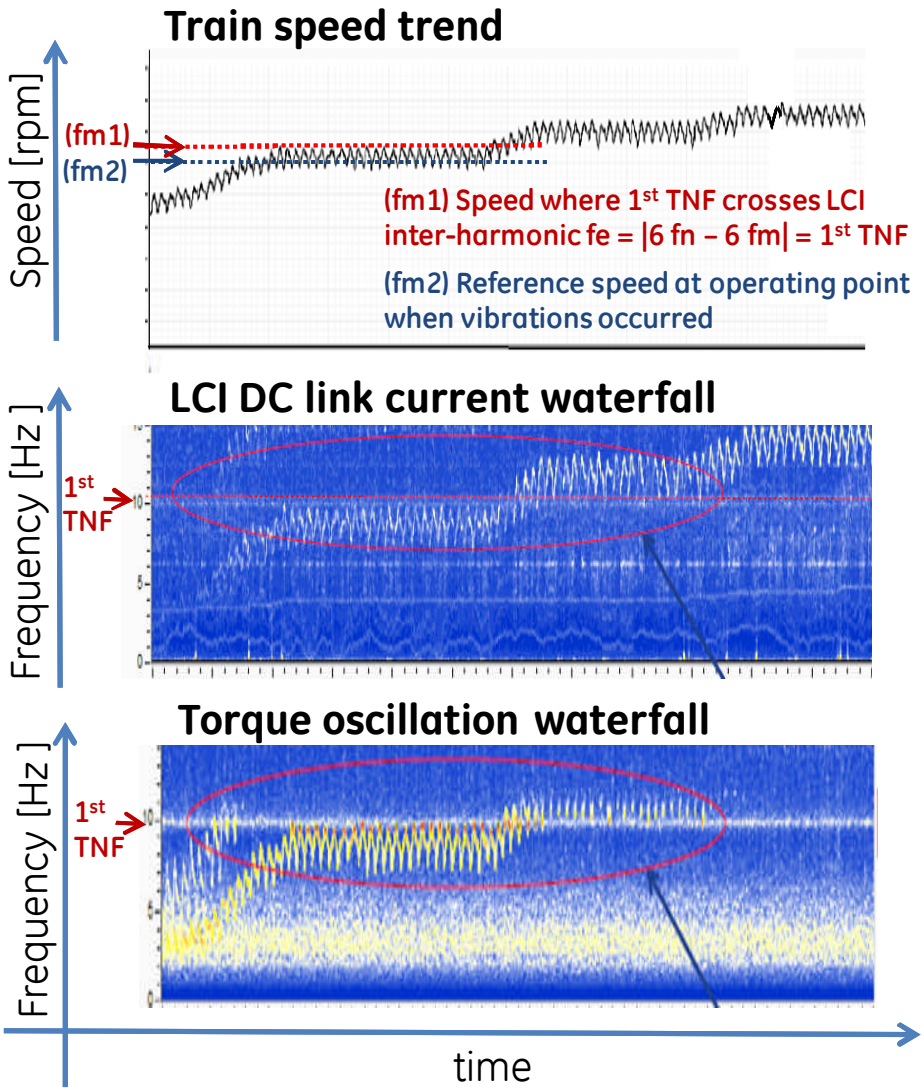
7.2 RCA - Speed ripple to 1st TNF excitation

System closed loop behavior:

In case of a **ripple** on the train **speed**....

.....a consequent variation of the **excitation frequency** (air gap torque ripple) is expected....

...this air gap torque ripple excites the 1st train torsional mode, producing a **torsional response at 1st TNF**.



8.1 Gear shafts mechanical response

Gearbox radial vibration response at 1st TNF was induced by torsional-lateral cross coupled effect, due to the kinematics of the geared system.

Effects due to the presence of torsional-flexural modes was excluded by means of a coupled rotor-dynamic analysis.

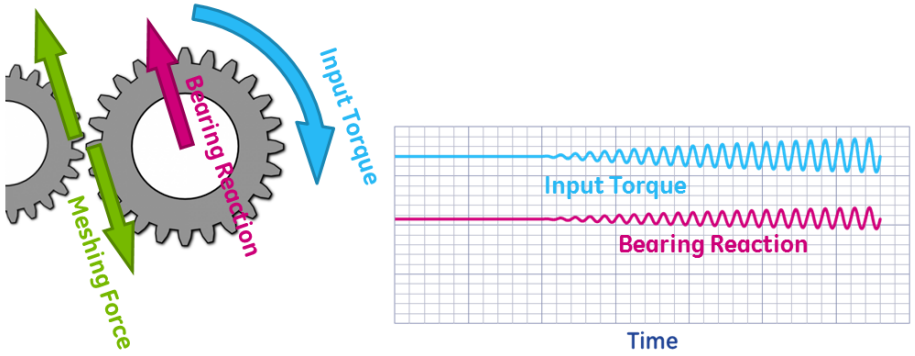
Torsional-lateral cross coupling

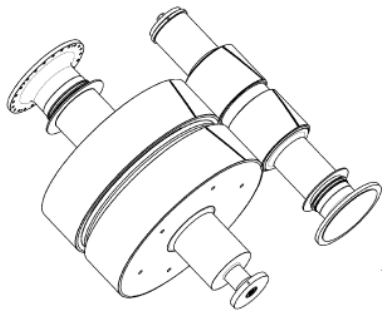
- Kinematic phenomenon
- Lateral vibration is the effect of torsional vibration
- The radial component of the meshing forces represents the shaft excitation source

VS

Torsional-flexural modes

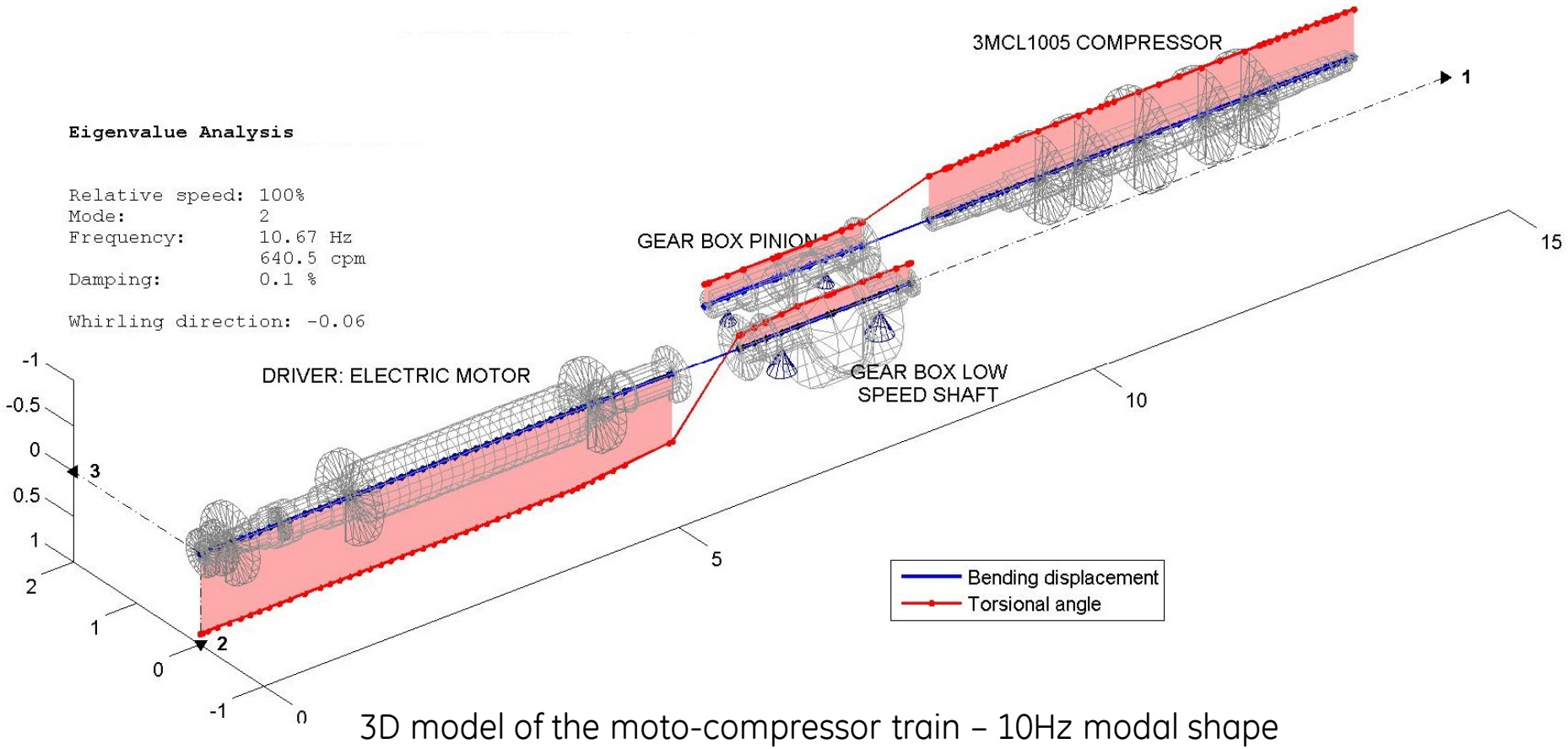
- Modal phenomenon
- Torsional and lateral vibrations coexist (no cause-effect relation): the modal shape exhibits a torsional and lateral deformation
- In this specific train the mode at 10 Hz is purely torsional





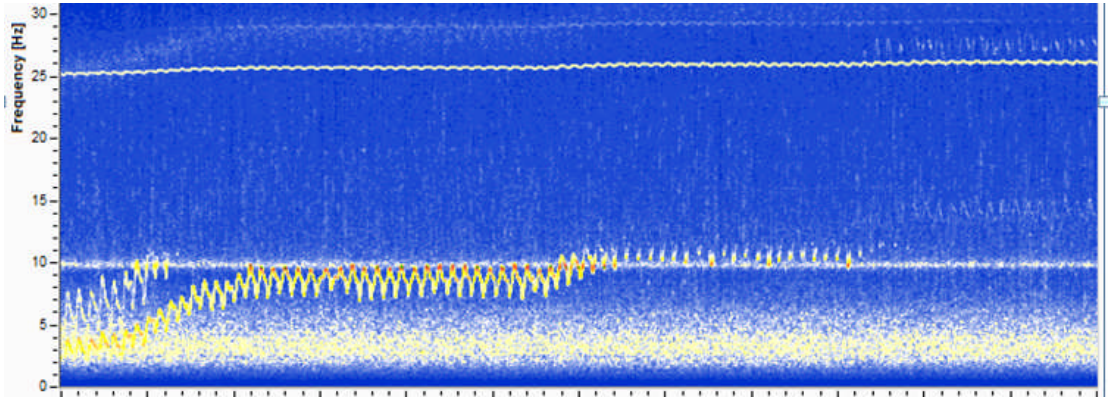
8.2 Gear shafts mechanical response

Results of coupled rotor-dynamic analysis: negligible flexural deformation associated to 1st TNF – the mode at 10Hz is purely torsional.

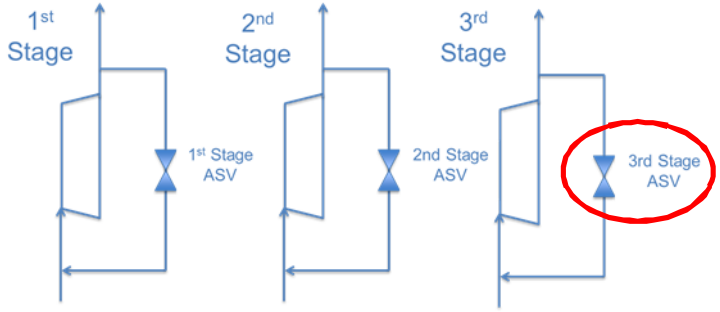


3D model of the moto-compressor train – 10Hz modal shape

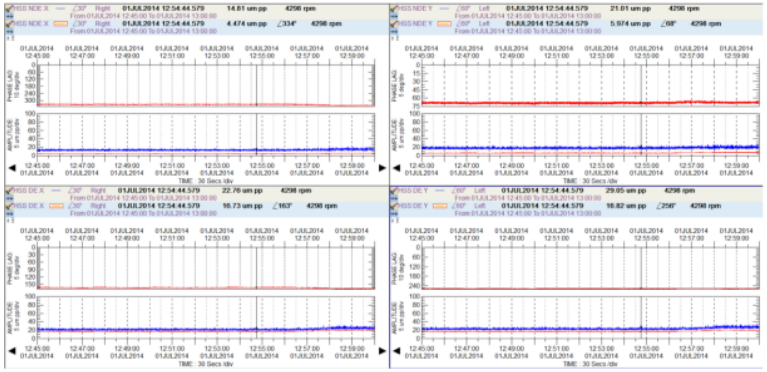
9. Site corrective action and outcomes



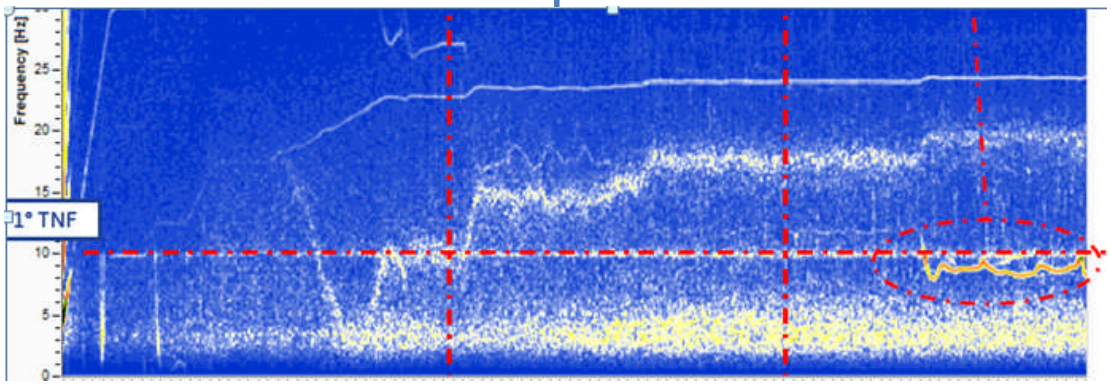
Measured torque Waterfall before CA



CA: 3rd Anti Surge Valve replacement



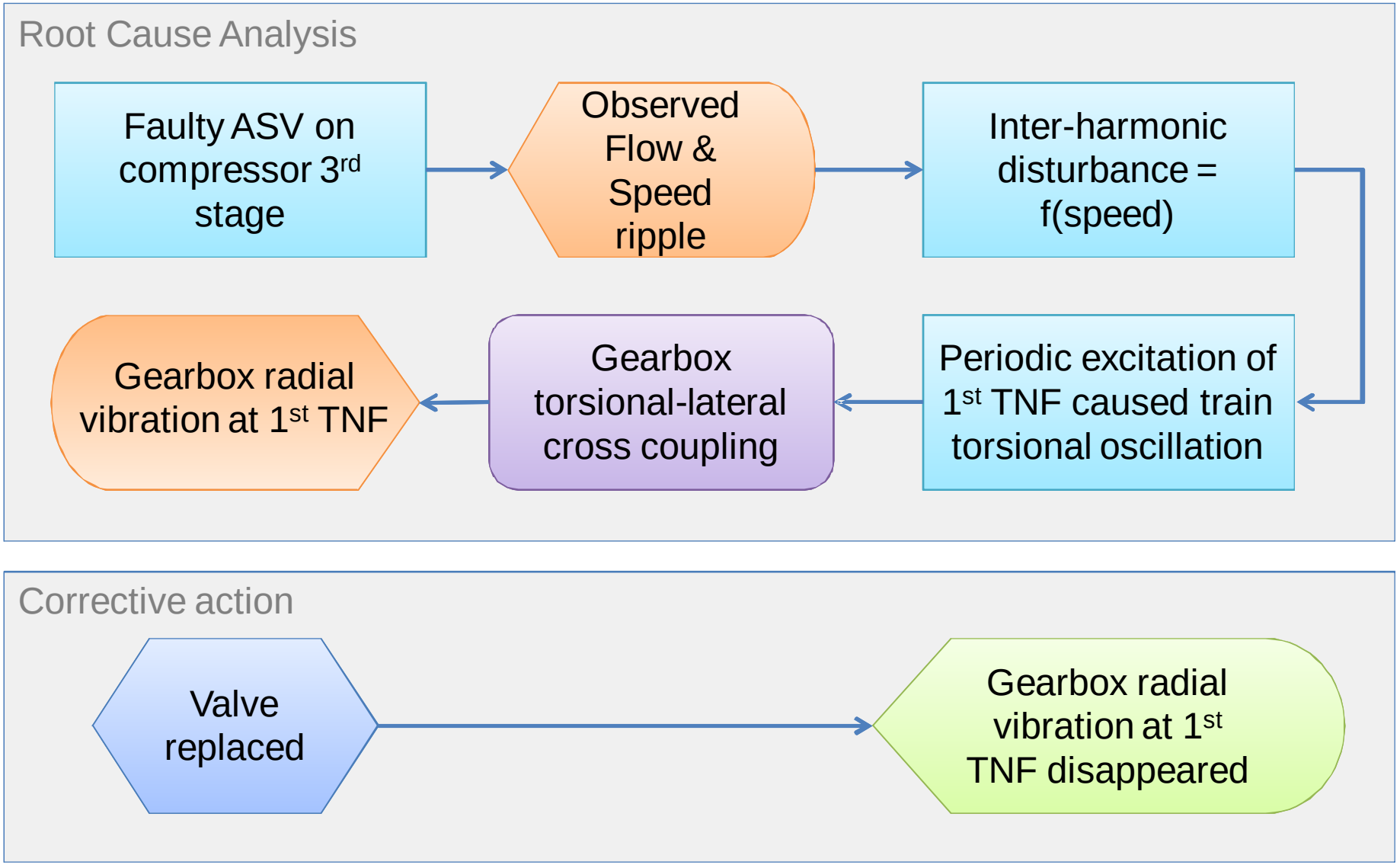
Improved GB HSS vibration



Measured torque Waterfall after CA

After ASV replacement, the GB rotor-dynamic behaviour is stable

10. Wrap-up – Cause/effects correlation



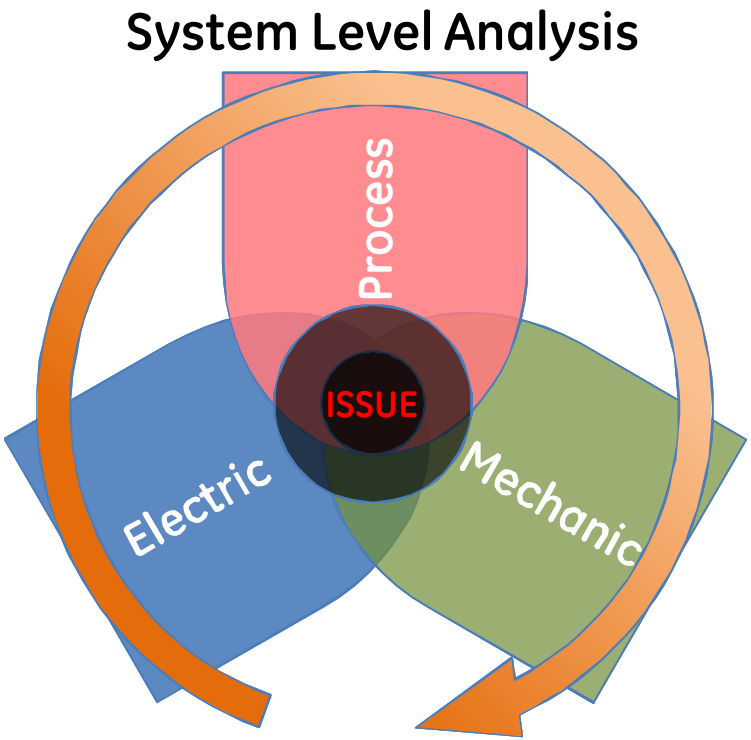
11. Highlights/Lessons Learnt

In a moto-compressor train, a cyclic process phenomenon induced a gear shaft vibration issue, through the electro-mechanical interaction.

- A rotating equipment abnormal rotor-dynamic behaviour can be caused by an apparently remote issue.

Faulty Compressor ASV → Radial vibration on Gearbox

- To troubleshoot complex interaction phenomena in operative conditions, it is needed an integrated data acquisition system, which is able to contextually acquire mechanical, electrical and process parameters .
- System level analysis is of fundamental importance for the VSDS driven compressor.



Thank you…

…any question?